EEG SIGNAL DECOMPOSTION AND IMPROVED SPECTRAL ANALYSIS USING WAVELET TRANSFORM

Bhatti, Muhammad Iqbal[1]; Pervaiz, Dr. Akhtar[2]; Baig, Mirza Haris[3]
[1 & 2] Biomedical Engineering Department, Sir Syed University Of Engineering and Technology, Karachi, Pakistan. Email: mibhatti@ssuet.edu.pk
[2] National University of Science & Technology, PNS Jauhar, Karachi, Pakistan.
Email: akhtarpervez@hotmail.com

ABSTRACT

EEG (Electroencephalograph), as a noninvasive testing method, plays a key role in the diagnosing diseases, and is useful for both physiological research and medical applications. Wavelet transform (WT) is a new multi-resolution time-frequency analysis method. WT possesses localization feature both in time and frequency domains. It acts as a group of band-pass filters decompose mixed signal into signals at frequency bands. Using the dyadic wavelet transform, the EEG signals are successfully decomposed and denoised.

In this paper we also use a 'quasi-detrending' method for classification of EEG spectrum where the level of detrending or differencing is made to vary. Difference in time domain acts as a high pass filter in the frequency domain. Therefore the low frequency values in the delta range can be ignored and this is a saving in computation time since delta range values do not correspond to any normal conscious human mental tasks. We also show that using discrete PSD (power spectral densities) values in the range below 30 Hz gives better classification results than using the delta, theta, alpha and beta power band values used by some authors.

Keywords: **EEG, Time-Frequency Analysis (TFA), Wavelet Transform (WT) Spectral Analysis, Quasi-detrending**

INTRODUCTION:

Recent years, the time-frequency analysis (TFA) has been successfully applied in some biomedical signals to detect both temporal and spectral features of biomedical signals. Wavelet transform (WT) is one of the TFA, and has been used successfully in many applications. In this paper, wavelet transform is applied to analyze and decompose the time-varying and non-stationary EEG signal, investigate its time-frequency characteristics, and remove the noise.

Further stationary transformation through the removal of low frequency trends is often a preliminary step to estimating a spectrum and failure to do so can lead to misleading power spectrum. Linear trends can be removed by first and second differencing while logarithmic differences are used for cyclical trends performed at any instant of time. After decomposing and denoising, we use a 'quasi-detrending' method proposed by Nerlove [11]. Nerlove has suggested of transforming the original time series into quasi-detrended time series by

(1) $$Z(n) = X(n) - K(x)(n-1),$$

where x(n) is the original time series, z(n) is the transformed series, n is the sampling point and k is the quasi-detrending factor. Higher level detrending would remove too much power from the signal in the low frequency range and might serve to worsen the spectral estimation. As such, an optimal value of k would give the least distortion while also removing linear trends in the power spectrum. we have investigated the performance of the spectrum with different values of k.

Fig. 1 shows an example where 0.5 quasi-detrending removes low frequency cycles but maintains the spectral peak as before detrending thereby improving the quality of the spectrum.

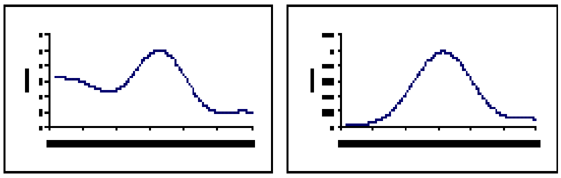

Figure 1: PSD (a) without detrending (b) with 0.5 quasi-detrending

METHOD

WT possesses well localization feature [3] both in time and frequency domains. It acts as a group of band-pass filters to decompose mixed signal into signals at different frequency bands. Mallat [1] [2] [4] fast algorithm of wavelet transform is used to decompose and reconstruct EEG signals. Adopting this algorithm, signals are decomposed to wavelet coefficients in different scales. Some coefficients related to noises are discarded, and the remained signals are reconstructed by inverse WT, then noises can be removed.

Mallat proved that the average density of modulus maxima of a white noise is inversely proportional to the scale s of WT. With the increase of scale, WT of EEG and noises present different inclination. Energy of noises concentrate on 21 scale and decrease significantly when the scale increases, while EEG concentrates mainly on scales 22 -25. By eliminating wavelet coefficients of small scales, denoised EEG is reconstructed by other scales, and the

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Abstract

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useful signals of EEG are well reserved while noises are removed effectively.

We now apply the of Quasi-detrending method to improve the spectral analysis of the EEG data obtained, the level of detrending is made to vary. Detrending in time domain acts as a high pass filter in the frequency domain. Therefore the low frequency values in the delta range (0-3 Hz) can be ignored and this is a saving in computation time since delta range values do not correspond to any normal conscious human mental tasks. The EEG power spectral densities (PSD) are extracted using Wiener – Khintchine theorem with Tukey window smoothing with 25% truncation point for frequencies up to 30 Hz. The EEG signals extracted are from 6 channels: C3, P3 and O1 from the left hemisphere and C4, P4 and O2 from the right hemisphere, in the standard 10-20 positioning scheme. The subjects are seated in a sound controlled booth with dim lighting and noiseless environment. The electrodes are connected through a bank of amplifiers and band-pass filtered from 0.1--100 Hz. The data was sampled at 250 Hz with a 12-bit A/D converter mounted on a computer. Four subjects are studied with two different mental tasks namely a complex multiplication task and a visual task imagining an image being rotated about an axis. These two tasks were chosen since they elicit different hemispheric response [10]. Data was recorded for 10 seconds during each task. With a 250 Hz sampling rate, each 10 second trial produces 2,500 samples per channel. Each EEG signal is segmented with a half-second window and a quarter-second overlap.

A Fuzzy ARTMAP (FA) [8] classifier is used to classify these 6 channels of EEG. Vigilance parameter for Fuzzy ART a module was fixed at 0.9. For all the experiments, 50% of available patterns are used for training while the rest 50% are used for testing as shown in figure 2

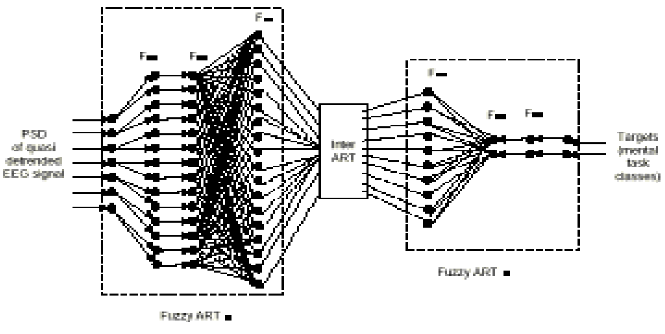

Figure 2: Fuzzy ARTMAP network structure as used in this paper

RESULTS

Using the dyadic wavelet transform, we successfully decompose the EEG signals to the alpha rhythm (8-13Hz), beta rhythm (14-30Hz) and theta rhythm (4-7Hz) as shown in Fig.3, and effectively remove the noise trembles in EEG while the useful information of EEG are well reserved so as to improve SNR (Signal Noise Ratio) as shown in Fig. 4.

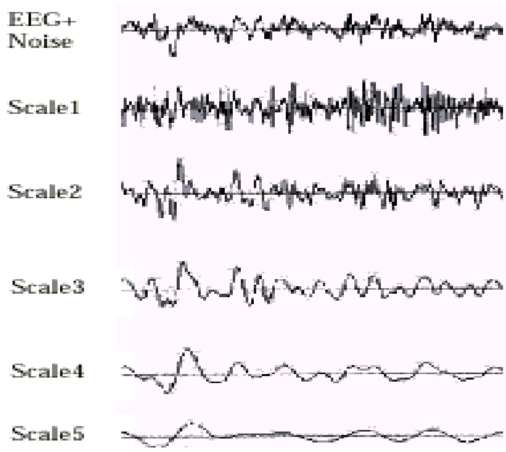

Figure 3: Noisy EEG signal and its wavelet transform at different scales.

Figure 4: EEG and its denoising (a) EEG signal with noise (b) denoised EEG

The results of the 'quasi-detrending' of the obtained EEG signal at a time instant improves the FA classification performance from 83.97% to 91.67% across all four subjects as compared to FA classification without detrending and with all other parameters fixed. The complete results are shown in Table 1. We can also see from this table that any quasi-detrending improves the performance with k=1 giving the best results for subject 1,2 and 4, while k=0.75 gives the best results for subject 3.

Table 1: Fuzzy ARTMAP classification for quasi-detrended signals

6 channels of PSD	1st user	2nd user	3rd user	4th user	All users
k=0: No detrending	84.62	74.36	94.88	74.4	83.97
k=0.25 detrending	84.62	79.49	94.88	76.92	84.62
k=0.5 detrending	84.62	89.74	94.88	76.92	91.03
k=0.75 detrending	92.31	87.10	97.44	79.49	84.62
k=1.0 detrending	97.44	89.74	94.88	76.92	91.67

Table 2 shows the results of another experiment. This table shows improvement of using discrete PSD values in the range below 30 Hz rather than using the delta, theta, alpha and beta power band values used by some authors [9-10]

Table 2: Fuzzy ARTMAP performance for discrete PSD values and band power values

	1st user	2nd user	3rd user	4th user	All users
4 to 30Hz PSD (without detrending)	84.62	74.36	94.88	74.4	83.97
4 band power values (without detrending)	69.23	66.67	94.88	74.36	78.85

CONCLUSION

The main advantage of wavelet transform is to provide simultaneous information on frequency and time location of the signal. By wavelet transform, EEG can be decomposed into different detail components or various frequency bands, and the noise also can be rejected effectively according to the different behavior of WT coefficients of signal and noise. Doctors may use those detail components and denoised EEG for further clinical analysis [7]. It is indicated that WT provides a promising method to characterize the EEG and remove the noise.
The quasi-detrending gives improved performance than without detrending and that discrete PSD values below 30 Hz perform better than using band power values. The results also show that it is possible to discriminate accurately between different mental tasks using the improved EEG spectrum and this can be used as a form of communication for paralysed patients [10].

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